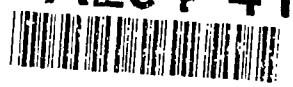
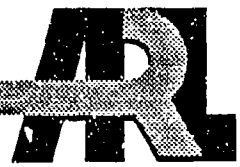


(2)

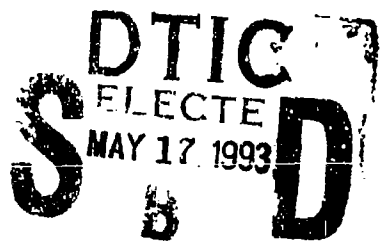
ARMY RESEARCH LABORATORY



# Vivacity Calculation, Rolled Ball, and Rosette Grain Form Function and Editing Capability Update to the Closed-Chamber Data Analysis Program BRLCB

William F. Oberle

ARL-MR-61 April 1993








## NOTICES

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | April 1993 | Final, Jun 92 - Jan 93 |

**4. TITLE AND SUBTITLE**

Vivacity Calculation, Rolled Ball, and Rosette Grain Form Function and Editing Capability Update to the Closed-Chamber Data Analysis Program BRLCB

**5. FUNDING NUMBERS**

DA311880
IF2Z9W
9XDGS3

**6. AUTHOR(S)**

William F. Oberle

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

U.S. Army Research Laboratory
ATTN: AMSRL-WT-PA
Aberdeen Proving Ground, MD 21005-5066

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B (Tech Lib)
Aberdeen Proving Ground, MD 21005-5066

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

ARL-MR-61

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

Updates to the closed-chamber data analysis program BRLCB are documented. The updates include vivacity calculations, grain geometry form functions for rosette and rolled ball propellants, and improved editing capabilities.

**14. SUBJECT TERMS**

closed-bomb, closed-chamber, burning rate, propellants, rolled ball propellant

**15. NUMBER OF PAGES**

43

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK.

## LIST OF FIGURES



## LIST OF TABLES

INTENTIONALLY LEFT BLANK.

## 1. INTRODUCTION

Although the Closed-Chamber Data Analysis Program BRLCB (Oberle and Kooker 1993)[1] was originally developed to support the work of the High Pressure Combustion Research Team of the Propulsion and Flight Division of the U.S. Army Research Laboratory, its use throughout the combustion community has resulted in the identification of additional features which if incorporated would enhance the programs utility. The requested features were: (1) calculations to determine vivacity, (2) inclusion of additional propellant grain form functions for rolled ball and rosette geometries, and (3) editing capabilities when dealing with multi-layered propellant grains (specifically, the ability to edit the input thermochemical information). The objective of this report is to document the inclusion of these options into the BRLCB program and provide the user with details on their use.

## 2. VIVACITY CALCULATION

In addition to the measurement of a propellant's burn rate, a comparison of the closed-chamber pressure-time curve with the pressure-time curve of a "standard" or baseline propellant is often used to characterize a propellant's combustion behavior. Some of the more common measurements/comparisons are dynamic vivacity, regular vivacity, relative force, and relative quickness. Generally, these comparisons or measurements involve the time derivative of the pressure (dP/dt), maximum pressure (Pmax), and instantaneous pressure (P). For example, dynamic vivacity is defined by

$$\text{Dynamic Vivacity} = \frac{dP/dt}{(P * Pmax)} . \qquad (1)$$

In order to facilitate the calculation of these quantities, an additional sub-option has been added to BRLCB. This sub-option is provided to the user just prior to exiting Option 5, Smooth Pressure/Time Data, of the Main Menu. Before exiting Option 5, the user is offered the option of performing the vivacity calculation. If the vivacity calculation is selected, the user is asked to provide a file name for the vivacity information. The BRLCB program places no restrictions on the file name format; however, a file extension of .VIV is recommended to prevent duplicating file names automatically generated by BRLCB. The format of the vivacity file is given in Table 1 and consists of five columns, as shown in the table. Although the dynamic vivacity is the only above mentioned quantity calculated, all the other

[1] Oberle, W. F., and D. E. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program Part I and II- Theory and User's Manual." ARL-TR-36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, January 1993.

quantities can be computed using the information supplied in the table, provided the "reference propellant" information required for relative force and quickness is known.

Table 1. Format of Vivacity File

| Column | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Quantity | Time | Pressure | Pressure/Pmax | dP/dt | Dynamic Vivacity |
| Units | s | MPa | (-) | MMPa/s[a] | 1/(MPa-s) |

[a] MMPa = Million MPa

To validate the computer coding of the vivacity sub-option, the interior ballistic code IBHVG2 (Anderson and Fickie 1987)† was used to simulate a pressure history (see Table 2 for specific input data utilized in the simulation).

Table 2. Input Parameters Utilized in IBHVG2 to Generate a Pressure History Used to Validate the BRLCB Vivacity Calculation

| Chamber Volume ($cm^3$) | 300 |
|---|---|
| Propellant: | |
| Geometry | Spherical |
| Diameter (cm) | 0.5 |
| Mass (g) | 91 |
| Impetus (J/g) | 1,140 |
| Flame Temperature (K) | 3,410 |
| Molecular Weight (-) | 24.87 |
| Covolume ($cm^3/g$) | 0.996 |
| Ratio of Specific Heats (-) | 1.225 |
| Density ($g/cm^3$) | 1.58 |

The pressure history generated by IBHVG2 was then used in BRLCB with the vivacity calculation option selected. Results from the BRLCB vivacity calculations were then compared with results obtained from directly computing the quantities listed in Table 1 from the pressure history. The percentage

† Anderson, R. D., and K. D. Fickie, "IBHVG2 - A User's Guide," BRL-TR-2829, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, July 1987.

difference between the two calculations is shown in Figure 1. As seen in the figure, the maximum percent error is approximately 0.02%. Considering that dP/dt was numerically calculated for both the BRLCB and the direct calculation the results are consider virtually identical. Thus, the vivacity routine included in BRLCB is correctly performing the desired calculations. Appendix A contains the code listing for the vivacity calculation added to BRLCB.

## 3. ROLLED BALL AND ROSETTE PROPELLANT GRAIN FORM FUNCTION

Two additional propellant grain form functions have been added to BRLCB—the rolled or squashed ball and a general rosette form function.

The geometry of the rolled ball is shown in Figure 2. Required dimensions are the overall grain diameter, D in Figure 2, and the thickness between the flat surfaces of the grain, T in Figure 2. The equations utilized to compute grain volume and surface area are those used in the interior ballistic code IBHVG2.

As described in the User's Manual (Oberle and Kooker 1993),† to verify the coding for a grain form function, IBHVG2 is used to generate a pressure history for a simulated closed-chamber firing. Input values utilized in IBHVG2 for the rolled ball grain geometry are given in Table 3.

The percent difference between the BRLCB derived burn rate and the assumed burn rate used in IBHVG2 (see Table 3) is shown in Figure 3. Due to the decimal accuracy of the input data from IBHVG2 and roundoff/truncation, errors associated with the numerical routines utilized in the program the maximum percent difference of less than 2% is consider insignificant (see User's Manual [Oberle and Kooker 1993]† for details). Thus, the coding for the rolled ball propellant is correct.

The geometry of the rosette form function is shown in Figure 4. The required dimensions are outer diameter; length; perforation diameter; inner, middle, and outer web. However, for the equations used to determine volume and surface area (identical to those used in IBHVG2), the inner and middle webs must be equal. In addition, the form function is generalized for 7, 19, 37, etc., perforations which are determined by entering the number of perforation rings. The relation between rings and the most common number of perforations is given in Table 4. The generalized relationship (n is number of rings and P

† Oberle, W. F., and D. E. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program Part I and II - Theory and User's Manual." ARL-TR 36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, January 1993.

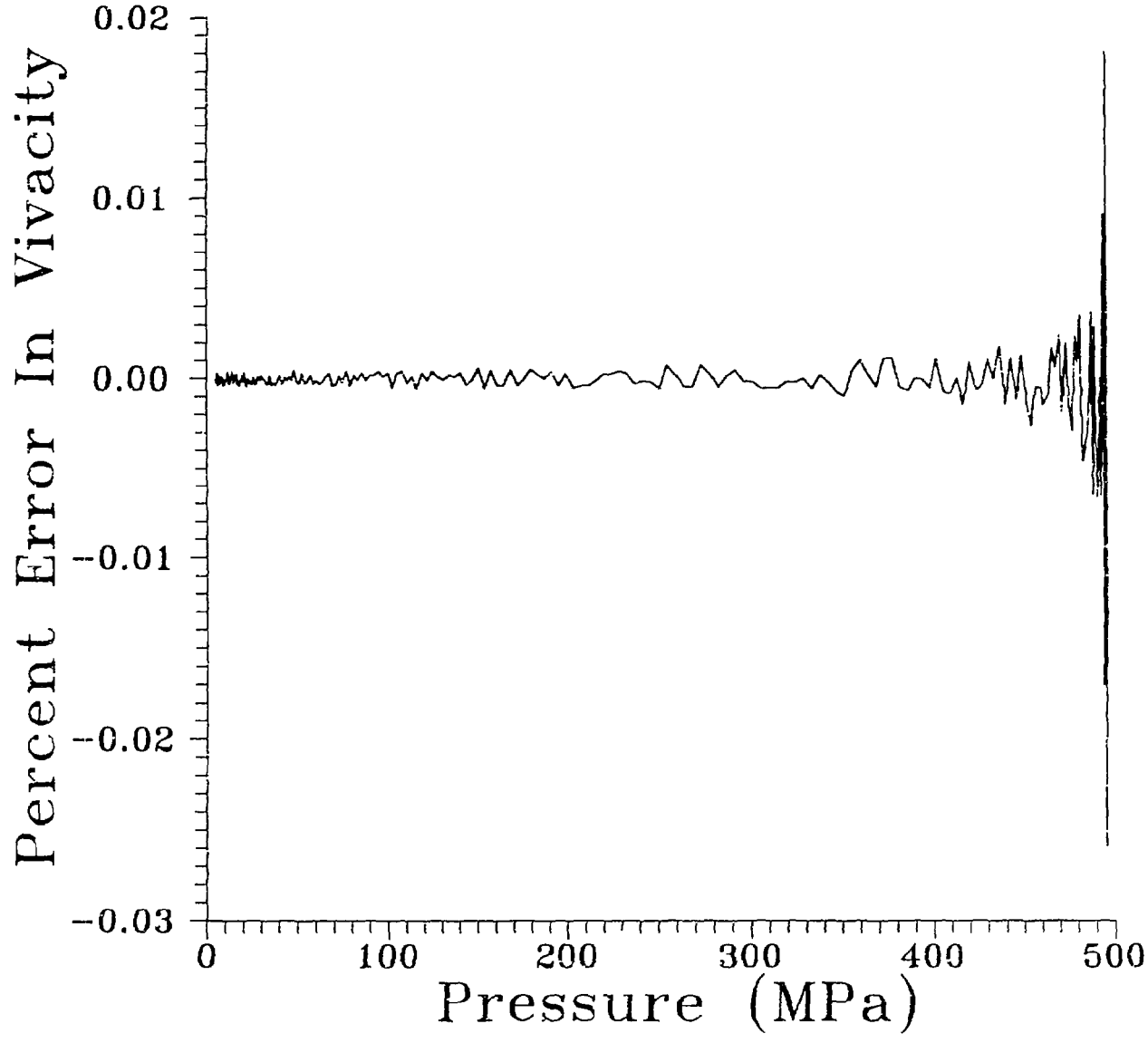



Figure 1. Percent difference between BRLCB dynamic vivacity calculation and direct calculation of the dynamic vivacity from the pressure-time data.

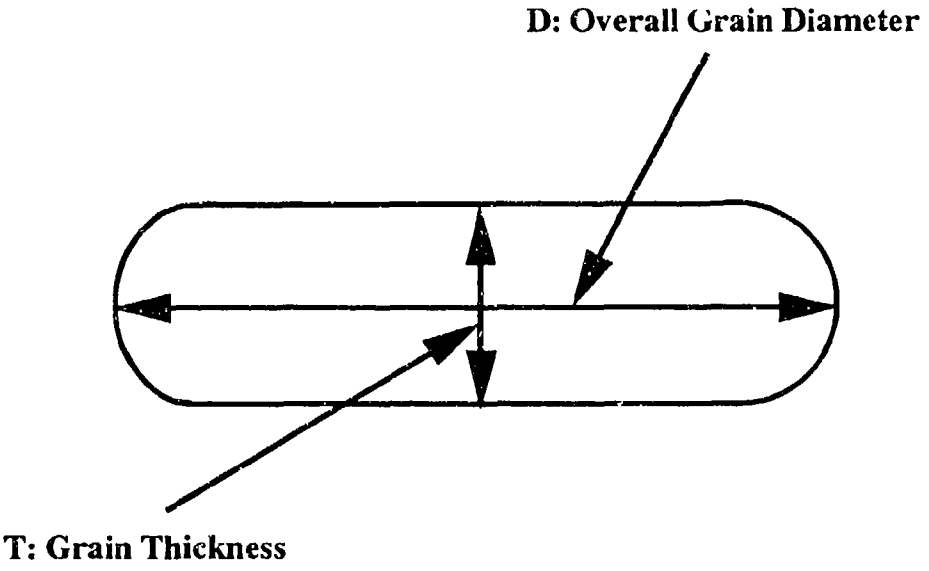



Figure 2. Schematic of rolled ball grain geometry.

Table 3. Input Parameters Used in IBHVG2 to Generate a Pressure History for Rolled Ball Grain Geometry

| Chamber Volume ($cm^3$) | 300 |
|---|---|
| Propellant: | |
| Geometry | Rolled Ball |
| Overall Diameter (cm) | 0.01 |
| Thickness (cm) | 0.005 |
| Mass (g) | 91 |
| Impetus (J/g) | 1,140 |
| Flame Temperature (K) | 3,410 |
| Molecular Weight (g/g-mol) | 24.87 |
| Covolume ($cm^3/g$) | 0.996 |
| Ratio of Specific Heats (-) | 1.225 |
| Density ($g/cm^3$) | 1.58 |
| Burn Rate Law | |
| Coefficient (cm/s-$MPa^n$) | 0.16 |
| Exponent (-) | 0.908 |

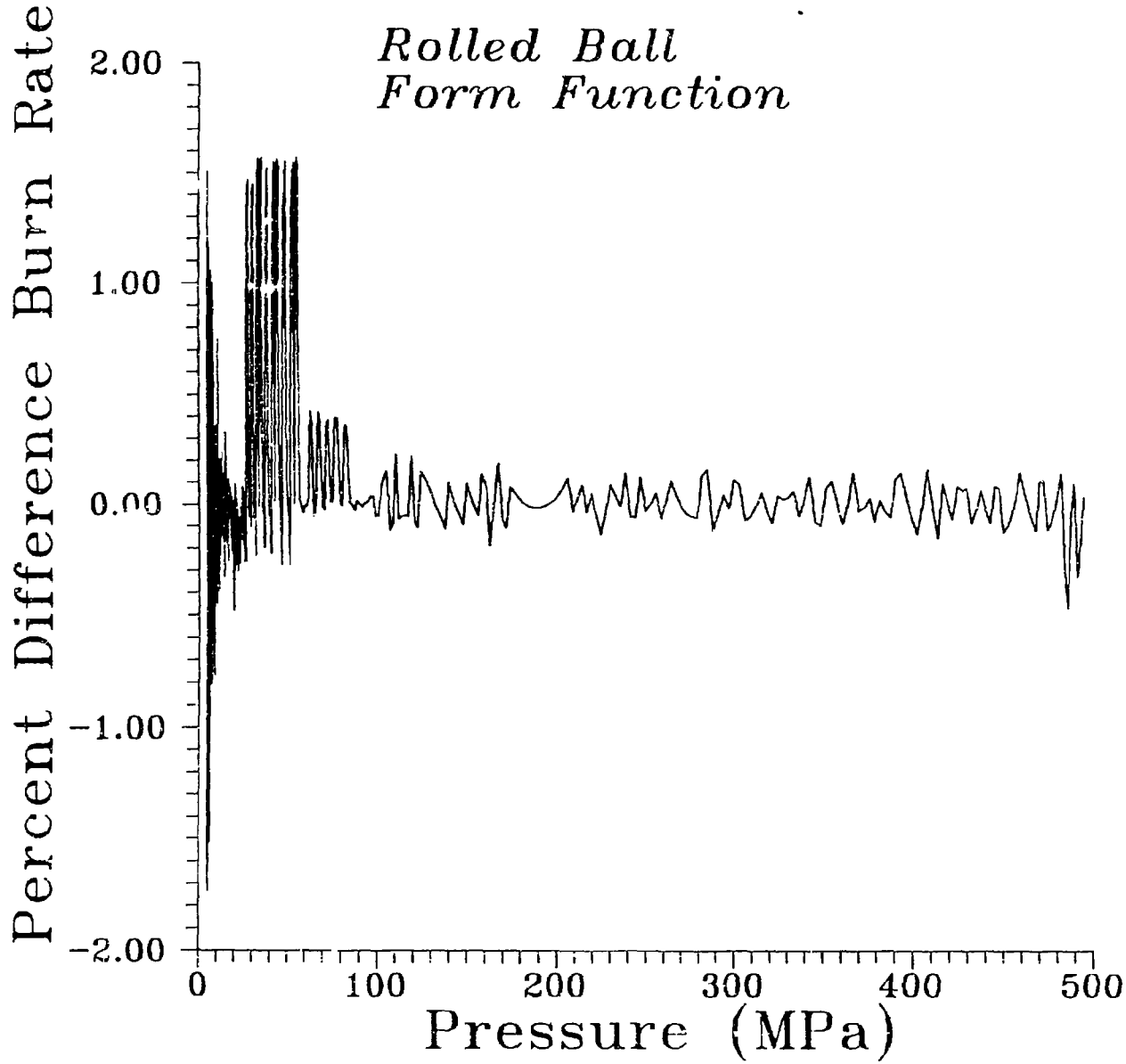



Figure 3. Percent difference between BRLCB derived burn rates and assumed burn rate, rolled ball form function.

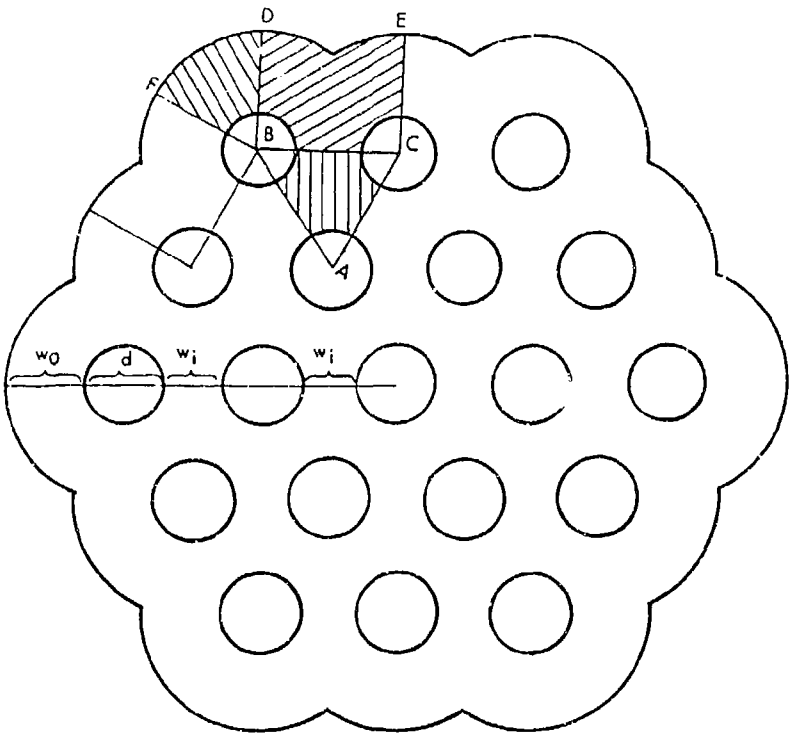



Figure 4. Schematic of rosette grain geometry.

Table 4. Relation Between Number of Rings and Perforations

| No. Rings | No. Perforations |
|---|---|
| 1 | 7 |
| 2 | 19 |
| 3 | 37 |

number of perforations) is

$$P = 3*n^2 + 3*n + 1 . \qquad (2)$$

A similar procedure to that used to validate the coding for the rolled ball form function was used for the rosette form function. Input values for the IBHVG2 simulation are given in Table 5. The percent differences between derived (BRLCB) and assumed burn rates are shown in Figure 5. Although the

maximum percent difference is slightly higher than for the rolled ball the results are felt to be acceptable. Thus, the rosette form function appears to be correctly coded.

Table 5. Input Parameters Used in IBHVG2 to Generate a Pressure History for Rosette Grain Geometry

| Chamber Volume ($cm^3$) | 300 |
|---|---|
| Propellant: | |
| Geometry | Rosette |
| Diameter (cm) | 2.9 |
| Length (cm) | 3.5 |
| Perf Diameter (cm) | 0.3 |
| Inner & Middle Webs (cm) | 0.2 |
| Outer Web (cm) | 0.3 |
| Mass (g) | 91 |
| Impetus (J/g) | 1,140 |
| Flame Temperature (K) | 3,410 |
| Molecular Weight (-) | 24.87 |
| Covolume ($cm^3/g$) | 0.996 |
| Ratio of Specific Heats (-) | 1.225 |
| Density ($g/cm^3$) | 1.58 |
| Burn Rate Law | |
| Coefficient ($cm/s\text{-}MPa^n$) | 0.16 |
| Exponent (-) | 0.908 |

## 4. EDITING CAPABILITY

For multi-layered propellant grains, 12 different values (propellant density and thermochemical information) are required by the code for each layer. Such a process is extremely susceptible to error (typing, transposing digits, etc.). Unfortunately, to correct an error, the original version of BRLCB required the user to re-enter all 12 values for each layer, again creating a situation which is extremely error prone. To alleviate this difficulty, an additional option (Option 0) has been incorporated into the BRLCB program. This option will allow the user to edit the physical properties (density and thermochemistry) of the propellant.

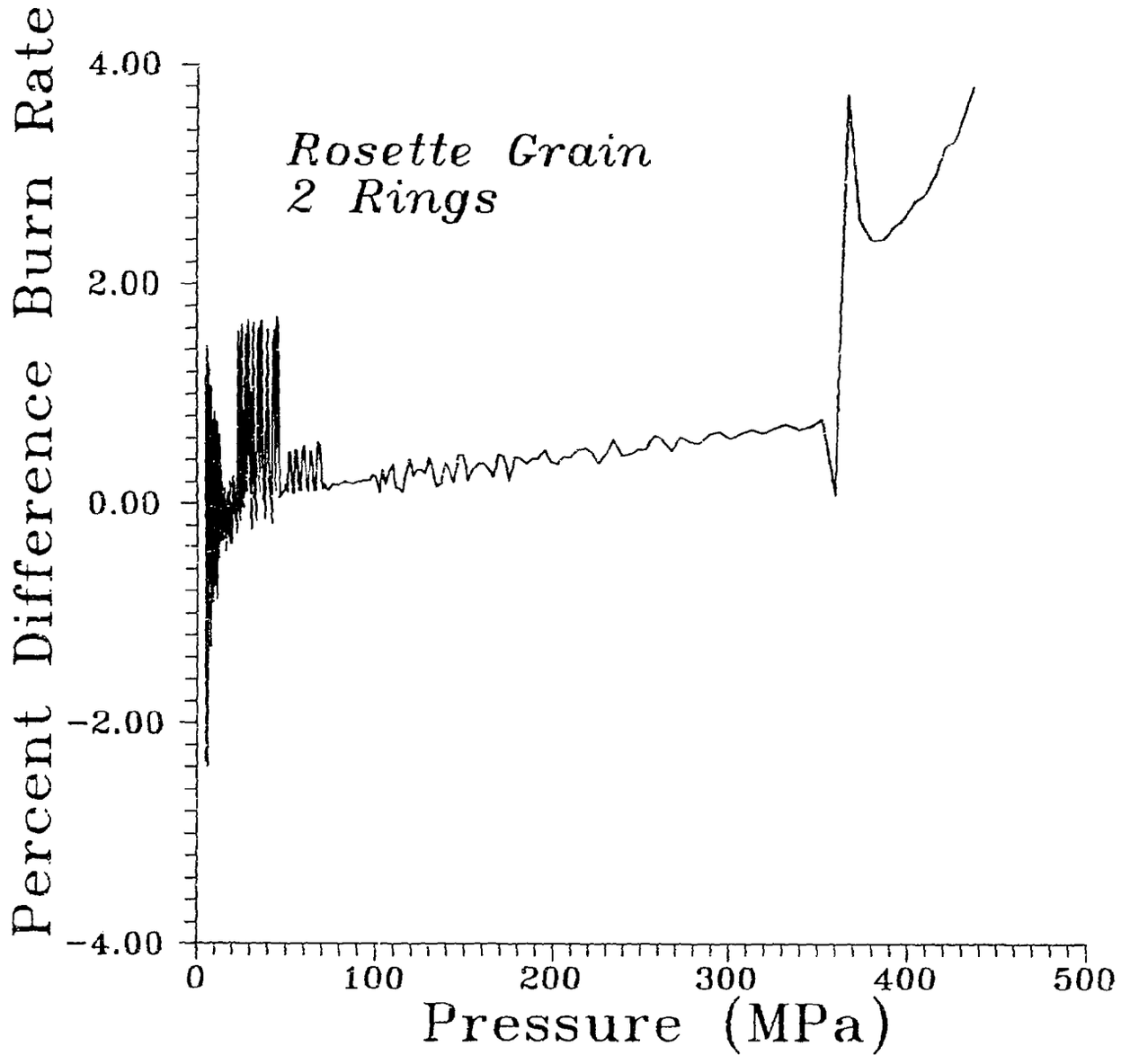



Figure 5. Percent difference between BRLCB derived burn rates and assumed burn rate, rosette form function.

The option is accessed from the Main Menu by typing a zero. The user is then requested to supply the name of the Master Information File (.MAS extension) containing the propellant data to be corrected. After entering the file name, the user will be allowed to edit the physical properties of each layer of the propellant material. In operation, the program reads the indicated Master Information File, creates a file named EDITFL with the format shown in Table 6 (example is a three-layer grain) and then invokes the EMACS editor JOVE (program EDITIN.FOR, see Appendix B). After the user completes editing (JOVE is exited by typing ESC-Z, escape key followed by the letter z), the Master Information File is rewritten (program EDOUT.FOR, see Appendix C). *THE NEW INFORMATION WILL OVERWRITE THE* ORIGINAL MASTER INFORMATION INDICATED BY THE USER. THIS OPTION SIMPLY EDITS AN EXISTING MASTER INFORMATION FILE AND DOES NOT CREATE A NEW FILE.

Table 6. Example of EDITFL File

| | | Number of Layers: 3 |
|---|---|---|
| LAYER #: 1 | | |
| Property | Beginning Layer | End of Layer |
| Impetus (J/g) | 1,100.00 | 1,200.00 |
| Flame Temp. (K) | 3,100.00 | 3,200.00 |
| Density (g/cm$^3$) | 1.500000 | 1.600000 |
| Mol. Wt. | 24.000000 | 25.000000 |
| Covolume (cm$^3$/g) | 1.000000 | 14.100000 |
| Gamma | 1.200000 | 1.210000 |
| LAYER #: 2 | | |
| Property | Beginning Layer | End of Layer |
| Impetus (J/g) | 1,200.00 | 1,250.00 |
| Flame Temp. (K) | 3,200.00 | 3,300.00 |
| Density (g/cm$^3$) | 1.400000 | 1.450000 |
| Mol. Wt. | 25.000000 | 27.000000 |
| Covolume (cm$^3$/g) | 1.200000 | 1.210000 |
| Gamma | 1.300000 | 1.310000 |
| LAYER #: 3 | | |
| Property | Beginning Layer | End of Layer |
| Impetus (J/g) | 1,300.00 | 1,400.00 |
| Flame Temp. (K) | 3,400.00 | 3,450.00 |
| Density (g/cm$^3$) | 1.400000 | 1.500000 |
| Mol. Wt. | 22.000000 | 21.000000 |
| Covolume (cm$^3$/g) | 1.300000 | 1.400000 |
| Gamma | 1.220000 | 1.250000 |

APPENDIX A:

LISTING OF CODE ADDED TO BRLCB FOR VIVACITY CALCULATION

INTENTIONALLY LEFT BLANK.

```
C*****************************************************************
C***************** VIVACITY CALCULATION CAN BE ADDED HERE ********
C*****************************************************************
 353    CALL CLEAR
        WRITE(*,2781)
 2781   FORMAT(///,' Do you wish to compute vivacity information?',
     1/,'    (1=Yes, 2=No)')
        WRITE(*,*)'Enter your choice.'
        READ(*,*)IKLB
        IF (IKLB .EQ. 1) THEN
        WRITE(*,*)'Enter a file name for the vivacity information.'
        READ(*,2782)VIVFIL
 2782   FORMAT(A20)
        OPEN(UNIT=8,FILE=VIVFIL)
        WRITE(8,2783)
 2783   FORMAT(' Time (sec)    Pressure (MPa)    P/PMAX          DP/DT
     1     Dynamic Vivacity',
     2/,' DP/DT has units of million MPa/sec',
     3/,' Dynamic Vivacity has units 1/(MPa*sec)',
     4/,'*************************************************',
     5//)
        ENDIF
        OPEN(UNIT=3,FILE = A1(14), STATUS = 'NEW',ERR=86)
        REWIND(3)
        IST=1
        IF (NP .GT. 999) THEN
        IST=NP-990
        ENDIF
        DO 60 I =IST, NP
        TX=(I-IST)*A3(42)/1000.
C        TX=T(I)
        IF (ITYPE .EQ. 5) THEN
        WRITE(3,*)TX,PR(I),PDOT(I),EE(I)
        ELSE
        WRITE(3,*) TX,PR(I),PDOT(I)
        ENDIF
        IF (IKLB .EQ. 1) THEN
        POPMAX=PR(I)/A3(43)
        VIVY=1.E6*PDOT(I)/(PR(I)*A3(43))
        WRITE(8,2784)TX,PR(I),POPMAX,PDOT(I),VIVY
 2784   FORMAT(5F16.6)
        ENDIF
 60     CONTINUE
        CLOSE(UNIT=3)
        CLOSE(UNIT=8)
```

INTENTIONALLY LEFT BLANK.

APPENDIX B:

LISTING - PROGRAM EDITIN.FOR

INTENTIONALLY LEFT BLANK.

```
      PROGRAM EDITIN
      CHARACTER*20 FNAME1, A2 (6)*80, A1 (20), EDITFL
      DIMENSION A3 (100), P (11, 15, 5)
      WRITE (*, *) 'This option only applies to editing the'
      WRITE (*, *) 'thermochemistry of a multi-layered grain.'
      WRITE (*, *) 'Other editing can be achieved by selecting'
      WRITE (*, *) 'Option 1, Create Master Information File.'
      WRITE (*, *)
 1000 CONTINUE
      WRITE (*, *) 'Enter the file name of the master file '
      WRITE (*, *) 'which is to be edited.  '
      WRITE (*, *) 'Include drive and file extension if necessary.'
      IFGZ = 1
      READ (*, 5000) FNAME1
 5000  FORMAT(A20)
      OPEN (UNIT = 9, FILE = FNAME1, STATUS = 'OLD', ERR = 1010)
      REWIND (UNIT = 9)
      GO TO 1020
 1010 CONTINUE
      WRITE (*, 6000)
 6000  FORMAT(20X,'The indicated master file does not exist, try again.'
     1)
      PAUSE
      GO TO 1000
C*************************************************************************
C********** READING OLD MASTER FILE TO BUILD FROM **********************
C*************************************************************************
 1020 CONTINUE
      DO 1030 I = 1, 6
         READ (9, 5010) A2 (I)
 1030 CONTINUE
 5010  FORMAT(A80)
      DO 1040 I = 1, 20
         READ (9, 5000) A1 (I)
 1040 CONTINUE
      DO 1050 I = 1, 100
         READ (9, *) A3 (I)
 1050 CONTINUE
      DO 1060 I = 1, 11
         DO 1070 J = 1, 15
            DO 1080 K = 1, 5
               READ (9, *) P (I, J, K)
 1080       CONTINUE
 1070    CONTINUE
 1060 CONTINUE
      CLOSE (UNIT = 9)
C*************************************************************************
C********** CREATING FILE WHICH WILL BE EDITED **************************
C*************************************************************************
      OPEN (UNIT = 9, FILE = 'EDITFL')
      REWIND (UNIT = 9)
C*************************************************************************
C************* NOW INFORMTAION FOR EACH LAYER ***************************
C*************************************************************************
```

```
      NUMLAY = INT (A3 (4) + .5)
      WRITE (9, 6010) FNAME1, NUMLAY
6010   FORMAT(A20,T30,'Number of Layers:',T47,I2)
      DO 1090 I = 1, NUMLAY
         WRITE (9, *)
         WRITE (9, 6020) I
6020   FORMAT('LAYER #:',I2)
         WRITE (9, 6030)
6030   FORMAT('Properity'T20,'Beginning Layer',T40,'End of Layer')
         WRITE (9, 6040) P (2, I, 1), P (2, I, 2)
6040   FORMAT('Impetus (J/g)',T20,F10.2,T40,F10.2)
         WRITE (9, 6050) P (3, I, 1), P (3, I, 2)
6050   FORMAT('Flame Temp. (K)',T20,F10.2,T40,F10.2)
         WRITE (9, 6060) P (4, I, 1), P (4, I, 2)
6060   FORMAT('Density (g/cc)',T20,F10.6,T40,F10.6)
         WRITE (9, 6070) P (5, I, 1), P (5, I, 2)
6070   FORMAT('Mol. Wt.',T20,F10.6,T40,F10.6)
         WRITE (9, 6080) P (6, I, 1), P (6, I, 2)
6080   FORMAT('Covolume (cc/g)',T20,F10.6,T40,F10.6)
         WRITE (9, 6090) P (7, I, 1), P (7, I, 2)
6090   FORMAT('Gamma',T20,F10.6,T40,F10.6)
1090  CONTINUE
      CLOSE (UNIT = 9)
      END
```

APPENDIX C:

LISTING - PROGRAM EDOUT.FOR

INTENTIONALLY LEFT BLANK.

```
      PROGRAM EDOUT
      COMMON A3 (100), P (11, 15, 5)
      CHARACTER*20 FNAME1, A2 (6)*80, A1 (20), LINE*80
C*************************************************************************
C****************** READING EDITED FILE: EDITFL ***********************
C*************************************************************************
      OPEN (UNIT = 9, FILE = 'EDITFL')
      REWIND (UNIT = 9)
      READ (9, 5000) FNAME1, NUMLAY
 5000  FORMAT(A20,T47,I2)
      OPEN (UNIT = 10, FILE = FNAME1)
      REWIND (UNIT = 10)
C*************************************************************************
C***************** READING MASTER FILE TO REBUILD ***********************
C*************************************************************************
 1000 CONTINUE
      DO 1010 I = 1, 6
         READ (10, 5010) A2 (I)
 1010 CONTINUE
 5010  FORMAT(A80)
      DO 1020 I = 1, 20
         READ (10, 5020) A1 (I)
 1020 CONTINUE
 5020  FORMAT(A20)
      DO 1030 I = 1, 100
         READ (10, *) A3 (I)
 1030 CONTINUE
      DO 1040 I = 1, 11
         DO 1050 J = 1, 15
            DO 1060 K = 1, 5
               READ (10, *) P (I, J, K)
 1060       CONTINUE
 1050    CONTINUE
 1040 CONTINUE
      CLOSE (UNIT = 10)
C*************************************************************************
C****** NOW INFORMTAION FOR EACH LAYER IS READ FROM FILE*****************
C*************************************************************************
      DO 1070 I =  , NUMLAY
         READ (9, 5030) LINE
 5030  FORMAT(A80)
         READ (9, 5030)
         READ (9, 5030)
         READ (9, 5040) P (2, I, 1), P (2, I, 2)
 5040  FORMAT(T20,F10.2,T40,F10.2)
         READ (9, 5050) P (3, I, 1), P (3, I, 2)
 5050  FORMAT(T20,F10.2,T40,F10.2)
         READ (9, 5060) P (4, I, 1), P (4, I, 2)
 5060  FORMAT(T20,F10.6,T40,F10.6)
         READ (9, 5070) P (5, I, 1), P (5, I, 2)
 5070  FORMAT(T20,F10.6,T40,F10.6)
         READ (9, 5080) P (6, I, 1), P (6, I, 2)
 5080  FORMAT(T20,F10.6,T40,F10.6)
         READ (9, 5090) P (7, I, 1), P (7, I, 2)
```

```
 5090  FORMAT(T20,F10.6,T40,F10.6)
         P (9, I, 1) = 1.98717/P (5, I, 1)
         P (9, I, 2) = 1.98717/P (5, I, 2)
         P (10, I, 1) = P (9, I, 1)/(P (7, I, 1) - 1.)
         P (10, I, 2) = P (9, I, 2)/(P (7, I, 2) - 1.)
         P (11, I, 1) = P (10, I, 1)*P (3, I, 1)
         P (11, I, 2) = P (10, I, 2)*P (3, I, 2)
 1070 CONTINUE
      CLOSE (UNIT = 9)
C*************************************************************************
C***************** INTEGRALS ARE UPDATED *****************************
C*************************************************************************
      CALL COMMASS
C*************************************************************************
C***************** MASTER FILE IS REWRITTEN **************************
C*************************************************************************
      OPEN (UNIT = 7, FILE = FNAME1)
 1030 CONTINUE
      DO 1090 I = 1, 6
         WRITE (7, 6000) A2 (I)
 6000  FORMAT(A80)
 1090 CONTINUE
      DO 1100 I = 1, 20
         WRITE (7, 6010) A1 (I)
 6010  FORMAT(A20)
 1100 CONTINUE
      DO 1110 I = 1, 100
         WRITE (7, *) A3 (I)
 1110 CONTINUE
      DO 1120 I = 1, 11
         DO 1130 J = 1, 15
            DO 1140 K = 1, 5
               WRITE (7, *) P (I, J, K)
 1140       CONTINUE
 1130    CONTINUE
 1120 CONTINUE
      CLOSE (UNIT = 7)
      END
C*************************************************************************
C*********************SUBROUTINE COMMASS**********************************
C*************************************************************************
      SUBROUTINE COMMASS
C*************************************************************************
C  Version 3.0, January 1992
C
C  THIS SUBROUTINE WILL COMPUTE THE INITIAL MASS PER LAYER AS WELL AS
C  THE INTEGRALS OF EACH PROPERTY
C
C*************************************************************************
      COMMON A3 (100), P (11, 15, 5)
      IGTYPE = INT (A3 (45) + .5)
      IF (IGTYPE .GT. 14) THEN
         IGTYPE = 15
      END IF
```

```
      NL = INT (A3 (4) + .5)
      IGQR = INT (A3 (31) + .5)
C*************************************************************************
C***************** STORAGE LOCATION FOR INTEGRAL ARE ZEROED ***************
C*************************************************************************
      DO 1000 I = 2, 11
         DO 1000 J = 1, 15
            P (I, J, 3) = 0.0
 1000 CONTINUE
      IF (IGQR .EQ. 1) THEN
         XI = 0.0
         CALL FORMT (IGTYPE, ASURF, VOLUNB, XI)
         P (8, 1, 3) = VOLUNB
         DO 1010 I = 2, 11
            P (I, 1, 3) = P (I, 1, 1)*P (8, 1, 3)
 1010    CONTINUE
         A3 (3) = P (4, 1, 3)
         RETURN
      END IF
      DO 1020 J = 1, NL
C*************************************************************************
C****************** DETERMINE X VALUES FOR INTEGRATION *******************
C*************************************************************************
         IF (J .EQ. NL) THEN
            XS = P (1, J, 1)
            XL = A3 (1)
         ELSE
            XS = P (1, J, 1)
            XL = P (1, J + 1, 1)
         END IF
C*************************************************************************
C*********************** ALWAYS 300 SUBDIVISIONS *************************
C*************************************************************************
         XDEL = XL - XS
         XSTEP = XDEL/300.
         DO 1030 I = 1, 301
            XI = XS + (I - 1)*XSTEP
C*************************************************************************
            CALL FORMT (IGTYPE, ASURF, VOLUNB, XI)
C*************************************************************************
            DO 1040 K = 2, 11
               PDEL = P (K, J, 2) - P (K, J, 1)
C*************************************************************************
C************************ INTEGRATION IS PERFORMED ***********************
C*************************************************************************
               FCN = ((PDEL/XDEL)*(XI - XS) + P (K, J, 1))*ASURF
               IF ((I .EQ. 1) .OR. (I .EQ. 301)) THEN
                  P (K, J, 3) = P (K, J, 3) + FCN
               ELSE
                  P (K, J, 3) = P (K, J, 3) + 2.*FCN
               END IF
 1040       CONTINUE
 1030    CONTINUE
         DO 1050 K = 2, 11
```

```
            P (K, J, 3) = P (K, J, 3)*(XDEL/600.)
 1050    CONTINUE
 1020 CONTINUE
C*************************************************************************
C********************** MASS OF SINGLE GRAIN ****************************
C*************************************************************************
      DO 1060 I = 1, NL
         A3 (3) = A3 (3) + P (4, I, 3)
 1060 CONTINUE
      RETURN
      END
C*************************************************************************
C*
C******************** SUBROUTINE FORMT ***********************************
C*
C*************************************************************************
C*
C         ICODE: code for type of grain
C         R : burn depth
C         GL: unburned grain length
C         D : unburned outer diameter
C         PD: unburned perforation diameter
C         WI, WM, WO: inner, middle and outer webs respectively
C
C   Output:
C         SFAREA: surface area
C         FRCSFA: surface area/initial surface area
C         VOLUNB: unburned volume
C         VOLBRN: burned volume
C         FRCBRN: burned volume/initial volume
C         VOLMAO: unburned volume of outer layer
C         VOLMBO: unburned volume of inner layer
C         VOLABR: burned volume of outer layer
C         VOLBBR: burned volume of inner layer
C
C*************************************************************************
      SUBROUTINE FORMT (ICODE, SFAREA, VOLUNB, R)
      COMMON A3 (100), P (11, 15, 5)
      DIMENSION S7 (4), S19 (3, 4)
      DATA RT/1.732050808/, PI3/1.047197551/, PI/3.141592654/
C*************************************************************************
C******************** SET GRAIN GEOMETRY *********************************
C*************************************************************************
      GL = A3 (7)
      D = A3 (8)
      PD = A3 (9)
      WI = A3 (10)
      WM = A3 (11)
      WO = A3 (12)
C*************************************************************************
C******** Set U = 2*(depth burned) and branch to grain type ************
C*************************************************************************
      U = 2.0*R
C*************************************************************************
```

```
C****** FINDING NUMBER OF RIGNS FOR ROSETTE GRAIN AND VALUES ***********
C*********************************************************************
C*********************************************************************
C*********** FINNDING NUMBER OF RIGNS FOR ROSETTE GRAIN ***************
C*********************************************************************
      IF (ICODE .EQ. 15) THEN
         NRGS = INT (A3 (45) - 150. + .5)
         NIZ = 6*NRGS*NRGS
         NOZ = 6*NRGS
         NCZ = 6
C*********************************************************************
C**************** TEST TO DETERMINE IF METHOD APPLICABLE **************
C*********************************************************************
         TOPP = WO*(PD + WO)
         BOTT = .5*WI*(PD + WI)
         IF (BOTT .GT. TOPP) THEN
            WRITE (*, *)
     1         'The grain geometry does not satisfy the assumption'
            WRITE (*, *)
     1         'made in determining the surface area and unburned'
            WRITE (*, *)
     1         'volume of a grain.  Use any results with caution.'
         END IF
         DPRIME = PD + U
C*********************************************************************
C**************** OUTER SLIVER IS COMPUTED ****************************
C*********************************************************************
         THETA = 2.*ACOS (AMIN1 (1., (WI + PD)/DPRIME))
         TOPP = WI/2. + PD/2.
         BOTT = WO + PD/2.
         ALPHA = ACOS (TOPP/BOTT)
         IF (U .LE. WO) THEN
            AREA1 = .5*(PI/2. - ALPHA)*((PD - U + 2.*WO)/2.)**2
            AREA2 = .5*((WI + PD)/2.)*(PD/2. + WO)*SIN (ALPHA)
            AREA3 = .5*(PI/2. - ALPHA)*(U/2.)**2
            AREA4 = .5*(PI/2. - (THETA/2.))*(DPRIME/2.)**2
            AREA5 = .5*((WI + PD)/2.)*(DPRIME/2.)*SIN (THETA/2.)
            EOZ = 2.*(AREA1 + AREA2 - AREA3 - AREA4 - AREA5)
            XLEN1 = (PI/2. - ALPHA)*((PD - U + 2.*WO)/2.)
            XLEN2 = (PI/2. - ALPHA)*(U/2.)
            XLEN3 = (PI/2. - (THETA/2.))*(DPRIME/2.)
            SOZ = 2.*(GL - U)*(XLEN1 + XLEN2 + XLEN3)
         ELSE
            TOPP = 2.*WO*(PD + WO)
            BOTT = PD + SQRT ((2.*WO - WI)*(2.*PD + 2.*WO + WI))
            IF (U .LE. (TOPP/BOTT)) THEN
               TOPP = PD*DPRIME + 2.*WO*(PD + WO)
               BOTT = DPRIME*(PD + 2.*WO)
               BETA = ACOS (TOPP/BOTT)
               TOPP = 2.*WO*(PD + WO) - (PD*U)
               BOTT = U*(PD + 2.*WO)
               GAMMA = ACOS (TOPP/BOTT)
               AREA1 = .5*(PD/2. + WO)*(DPRIME/2.)*
     1            SIN (ALPHA - THETA/2.)
```

```
               AREA2 = .5*(PD/2. + WO)*(DPRIME/2.)*SIN (BETA)
               AREA3 = .5*(ALPHA - BETA - THETA/2.)*(DPRIME/2.)**2
               AREA4 = .5*(PI/2. - ALPHA - GAMMA)*(U/2.)**2
               EOZ = 2.*(AREA1 - AREA2 - AREA3 - AREA4)
               XLEN1 = (PI/2. - ALPHA - GAMMA)*(U/2.)
               XLEN2 = (ALPHA - BETA - THETA/2.)*(DPRIME/2.)
               SOZ = 2.*(GL - U)*(XLEN1 + XLEN2)
            ELSE
               EOZ = 0.0
               SOZ = 0.0
            END IF
         END IF
C*************************************************************************
C**************** NOW CORNER IS COMPUTED *********************************
C*************************************************************************
         IF (U .LE. WO) THEN
            AREA1 = .5*PI/3.*((PD + 2.*WO - U)/2.)**2
            AREA2 = .5*PI/3.*(DPRIME/2.)**2
            ECZ = AREA1 - AREA2
            XLEN1 = PI/3.*((PD + 2.*WO - U)/2.)
            XLEN2 = PI/3.*(DPRIME/2.)
            SCZ = (GL - U)*(XLEN1 + XLEN2)
         ELSE
            ECZ = 0.0
            SCZ = 0.0
         END IF
C*************************************************************************
C**************** FINALLY THE INNER SLIVERS ******************************
C*************************************************************************
         SQRT3 = SQRT (3.)/2.
         TOPP = (WI + PD)/SQRT3 - PD
         IF (U .LE. TOPP) THEN
            AREA1 = .5*SQRT3*(WI + PD)**2
            AREA2 = .5*(WI + PD)*(DPRIME/2.)*SIN (THETA/2.)
            AREA3 = .5*(PI/3. - THETA)*(DPRIME/2.)**2
            EIZ = AREA1 - 3.*(AREA2 + AREA3)
            XLEN1 = (PI/3 - THETA)*(DPRIME/2.)
            SIZ = 3.*(GL - U)*XLEN1
         ELSE
            EIZ = 0.0
            SIZ = 0.0
         END IF
C*************************************************************************
C**************** SURFACE AREA AND UNBURNED VOLUME COMPUTED **************
C*************************************************************************
         E = NIZ*EIZ + NOZ*EOZ + NCZ*ECZ
         SFAREA = 2.*E + NIZ*SIZ + NOZ*SOZ + NCZ*SCZ
         VOLUNB = E*(GL - U)
         RETURN
      END IF
C*************************************************************************
C********************** ROLLED BALL GRAIN ********************************
C*************************************************************************
      IF (ICODE .EQ. 14) THEN
```

```
            DD = A3 (8) - A3 (7)
            TT = A3 (7) - U
            SFAREA = PI/2.*(DD**2 + 2.*TT**2 + PI*DD*TT)
            VOLUNB = TT*PI/2.*((DD**2)/2. + (TT**2)/3. + (PI*DD*TT)/4.)
            RETURN
         END IF
C*************************************************************************
C********************** CIGARETTE GRAIN ******************************
C*************************************************************************
         IF (ICODE .EQ. 13) THEN
            SFAREA = PI*D*D/4
            VOLUNB = (GL - R)*SFAREA
            RETURN
         END IF
C*************************************************************************
C****************** ALL OTHER GRAINS ARE HANDLED *************************
C*************************************************************************
         GO TO ( 1000, 1010, 1020, 1030, 1040, 1050, 1060, 1070,
        1    1080, 1090, 1100, 1110), ICODE
C*************************************************************************
C********************  CODE 1: 7-PERF GRAIN  *****************************
C*************************************************************************
C***  This part calculates the conditions before the grain burns.
C*************************************************************************
 1050 CONTINUE
         D = 3.0*PD + 2.0*(WI + WO)
         E0 = PI*(D**2 - 7.0*PD**2)/4.0
         S0 = PI*(D + 7.0*PD)*GL + 2.0*E0
         V0 = E0*GL
         WW = WI + PD
         DO 1120 K = 1, 3
            S7 (K) = WW
 1120 CONTINUE
         WEBC = AMIN1 (WO, WI, GL)
C*************************************************************************
C***  This part does the calculations for the burning grain.
C*************************************************************************
         GRL = AMAX1 (GL - U, 0.0)
         OD = D - U
         PRFD = PD + U
         IF (U .GT. WEBC) GO TO 1130
         E = PI*(OD**2 - 7.0*PRFD**2)/4.0
         SFAREA = PI*(OD + 7.0*PRFD)*GRL + 2.0*E
         FRCSFA = SFAREA/S0
         VOLUNB = E*GRL
         VOLBRN = V0 - VOLUNB
         FRCBRN = VOLBRN/V0
         RETURN
C*************************************************************************
C***  This part does the calculations for when the grain slivers. ******
C*************************************************************************
 1130 CONTINUE
         CALL GENIS (S7, PRFD, GRL, SF1, GV1)
         CALL GENOS (S7, PRFD, GRL, 0.5*OD, SF2, GV2)
```

```
      SFAREA = 6.0*(SF1 + SF2)
      FRCSFA = SFAREA/S0
      VOLUNB = 6.0*(GV1 + GV2)
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*****************************************************************
C******************  CODE 2: 1-PERF GRAIN  ***********************
C*****************************************************************
C***  This part calculates the conditions before the grain burns.
C*****************************************************************
 1030 CONTINUE
      D = PD + 2.0*WI
      E0 = PI*(D**2 - PD**2)/4.0
      S0 = PI*(D + PD)*GL + 2.0*E0
      V0 = E0*GL
      WEBC = AMIN1 (GL, WI)
C*****************************************************************
C*******  This part does the calculations for the burning grain. *******
C*****************************************************************
      IF (U .GE. WEBC) THEN
         GRL = 0.0
         E = 0.0
         GO TO 1140
      END IF
      GRL = GL - U
      OD = D - U
      PRFD = PD + U
      E = PI*(OD**2 - PRFD**2)/4.0
 1140 CONTINUE
      SFAREA = PI*(OD + PRFD)*GRL + 2.0*E
      FRCSFA = SFAREA/S0
      VOLUNB = E*GRL
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*****************************************************************
C******************  CODE 3: CORD GRAIN  *************************
C*****************************************************************
C***  This part calculates the conditions before the grain burns. ******
C*****************************************************************
 1010 CONTINUE
      S0 = GL*PI*D + PI*D**2/2.0
      V0 = GL*PI*D**2/4.0
C***  This part does the calculations for the burning brain.
      GRL = AMAX1 (GL - U, 0.0)
      OD = AMAX1 (D - U, 0.0)
      E = PI*OD**2/4.0
      SFAREA = PI*OD*GRL + 2.0*E
      FRCSFA = SFAREA/S0
      VOLUNB = GRL*PI*OD**2/4.0
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
```

```
C*************************************************************************
C******************  CODE 4: RECTANGULAR STRIP GRAIN   ******************
C*************************************************************************
 1020 CONTINUE
      S0 = 2.0*(GL*D + D*WI + GL*WI)
      V0 = GL*D*WI
      GRL = AMAX1 (GL - U, 0.0)
      DS = AMAX1 (D - U, 0.0)
      WIS = AMAX1 (WI - U, 0.0)
      SFAREA = 2.0*(GRL*DS + DS*WIS + WIS*GRL)
      FRCSFA = SFAREA/S0
      VOLUNB = GRL*DS*WIS
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*************************************************************************
C******************  CODE 5: SPHERICAL GRAIN  ****************************
C*************************************************************************
 1000 CONTINUE
      S0 = PI*D**2
      V0 = PI*D**3/6.0
      OD = AMAX1 (D - U, 0.0)
      SFAREA = PI*OD**2
      FRCSFA = SFAREA/S0
      VOLUNB = PI*OD**3/6.0
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*************************************************************************
C******************  CODE 6: SLOTTED-TUBE GRAIN  *************************
C*************************************************************************
C***  This part does the calculations before the grain burns. ***********
C*************************************************************************
 1040 CONTINUE
      SLOT = 0.5*WM
      SO = 0.5*D
      SI = 0.5*PD
      THETA = ASIN (SLOT/SO)
      ALPHA = ASIN (SLOT/SI)
      E0 = (PI - ALPHA)*(SO**2 - SI**2) + (SO - SI)**2*ALPHA
      S0 = 2.0*((PI - ALPHA)*SI + (PI - THETA)*SO + (SO*COS (THETA)
     1   - SI*COS (ALPHA)))*GL + 2.0*E0
      V0 = GL*E0
      WI = SO - SI
      WEBC = AMIN1 (GL, WI)
C*************************************************************************
C***  This part does the calculations for the burning grain. ***********
C*************************************************************************
      IF (U .GE. WEBC) THEN
         GRL = 0.0
         E = 0.0
         GO TO 1150
      END IF
      SLOT = 0.5*(WM + U)
```

```
      SO = 0.5*(D - U)
      SI = 0.5*(PD + U)
      GRL = GL - U
      THETA = ASIN (SLOT/SO)
      ALPHA = ASIN (SLOT/SI)
      E = (PI - ALPHA)*(SO**2 - SI**2) + (SO - SI)**2*ALPHA
 1150 CONTINUE
      SFAREA = 2.0*((PI - ALPHA)*SI + (PI - THETA)*SO + (SO*COS (THETA)
     1   - SI*COS (ALPHA)))*GRL + 2.0*E
      FRCSFA = SFAREA/S0
      VOLUNB = E*GRL
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*******************************************************************
C******************  CODE 7: ROUND-HEX 37-PERF GRAIN  ***************
C*******************************************************************
 1090 CONTINUE
      SO = 18.
      SI = 54.
      NPERF = 37
      D = 7.0*PD + 6.0*WI + 2.0*WO
      GO TO 1160
C*******************************************************************
C******************  CODE 8: ROUND-HEX 19-PERF GRAIN  ***************
C*******************************************************************
 1080 CONTINUE
      SO = 12.0
      SI = 24.0
      NPERF = 19
      D = 5.0*PD + 4.0*WI + 2.0*WO
C*******************************************************************
C******************  CALCULATIONS FOR CODES 7,8,10  ****************
C*******************************************************************
 1160 CONTINUE
      WW = WI + PD
      WW2 = WW**2
      PRFD = PD + U
      PRFD2 = PRFD**2
      GRL = AMAX1 (GL - U, 0.0)
      E = 0.0
      THETA = 2.0*ACOS (AMIN1 (WW/PRFD, 1.0))
      ALPHA = ACOS (AMIN1 ((2.0*WO + PD - U)/PRFD, 1.0))
      IF (U .LT. WO) E = 0.25*PI*((2.0*WO + PD - U)**2 - PRFD2)
      IF (THETA .GE. PI3) GO TO 1170
      E = E + SI*0.25*(WW2*RT - 1.5*PRFD2*(SIN (THETA) + PI3 - THETA))
 1170 CONTINUE
      IF (ALPHA .GE. 0.5*(PI - THETA)) GO TO 1180
      E = E + SO*0.125*(2.0*(2.0*WO + PD - U)*(2.0*
     1   WW - PRFD*SIN (ALPHA))
     2   - PRFD2*(SIN (THETA) + PI - 2.0*ALPHA - THETA))
 1180 CONTINUE
      IF (2.0*WO + PD .LT. WI) THEN
         WRITE (*, *) '*FORMT* BAD HEX PROP'
```

```
         PAUSE
         GO TO 1190
      END IF
      VOLUNB = E*GRL
C******************** TEST TO SEE IF GRAIN CONSUMED *********************
      IF (VOLUNB .LE. 0.0) THEN
         SFAREA = 0.0
         VOLUNB = 0.0
         GO TO 1190
      END IF
C************************NOW THE SURFACE AREA*****************************
      PH = D/2. - WO - PD/2.
      IF (U .EQ. 0.0) THEN
         SFAREA = 2.*E + GRL*PH*6. + NPERF*PI*PD*
     1      GRL + PI*GRL*(2*WO + PD)
         GO TO 1190
      END IF
C*************************NO SLIVERING YET*******************************
      IF ((WO .GT. U) .AND. (WI .GT. U)) THEN
         SFAREA = 2.*E + NPERF*(PD + U)*GRL*PI + 6.*PH*
     1      GRL + PI*(2.*WO + PD - U)*GRL
         GO TO 1190
      END IF
C********************* NOW SLIVERING ***********************************
      SFAREA = 2.*E
C************************ FIRST THE INNER SLIVERS **********************
      IF (THETA .GE. PI3) THEN
         GO TO 1200
      ELSE
         SFAREA = SFAREA + 1.5*PRFD*GRL*(PI3 - THETA)*SI
      END IF
 1200 CONTINUE
C**************** NOW THE OUTER SLIVERS & CORNERS **********************
C********************* CORNERS NOT CONSUMED ****************************
      IF (WO .GT. U) THEN
         SFAREA = SFAREA + PI*(PD + 2.*WO - U + PRFD)*GRL
      END IF
C************************NOW OUTER SLIVERS*******************************
      IF (ALPHA .LT. .5*(PI - THETA)) THEN
         SFAREA = SFAREA + (WW - PRFD*SIN (ALPHA))*GRL*SO +
     1      PRFD*GRL*(PI/2. - ALPHA - THETA/2.)*SO
      END IF
 1190 CONTINUE
      RETURN
C***********************************************************************
C*********************  CODE 9: 19-PERF GRAIN  *************************
C***********************************************************************
C*** This part calculates the conditions before the grain burns ********
C***********************************************************************
 1070 CONTINUE
      D = 5.0*PD + 2.0*(WI + WM + WO)
      E0 = PI*(D**2 - 19.0*PD**2)/4.0
      S0 = PI*(D + 19.0*PD)*GL + 2.0*E0
      V0 = E0*GL
```

```
      S19 (1, 1) = WI + PD
      S19 (2, 1) = S19 (1, 1)
      S19 (3, 1) = S19 (1, 1)
      S19 (1, 2) = 0.5*SQRT (3.0*(WM + PD)**2 + (WI + PD)**2)
      S19 (2, 2) = S19 (1, 2)
      S19 (3, 2) = S19 (1, 1)
      S19 (1, 3) = PD + 0.5*(WI + WM)
      S19 (2, 3) = S19 (1, 2)
      S19 (3, 3) = WM + PD
      S19 (1, 4) = S19 (1, 3)
      S19 (2, 4) = 2.0*S19 (1, 3)
      S19 (3, 4) = S19 (1, 3)*RT
      WEBC = AMIN1 (WO, WM, WI, S19 (1, 3) - PD, S19 (1, 2) - PD, GL)
C*************************************************************************
C*** This part does the calculations for the burning grain. ************
C*************************************************************************
      GRL = AMAX1 (GL - U, 0.0)
C*************************************************************************
      OD = D - U
      PRFD = PD + U
      IF (U .GE. WEBC) GO TO 1210
      E = 0.25*PI*(OD**2 - 19.0*PRFD**2)
      SFAREA = PI*(OD + 19.0*PRFD)*GRL + 2.0*E
      FRCSFA = SFAREA/S0
      VOLUNB = E*GRL
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
 1210 CONTINUE
      SUMSA = 0.0
      SUMGV = 0.0
      DO 1220 K = 1, 2
         CALL GENIS (S19 (1, K), PRFD, GRL, SA, GV)
         SUMSA = SUMSA + 6.0*SA
         SUMGV = SUMGV + 6.0*GV
 1220 CONTINUE
      CALL GENIS (S19 (1, 3), PRFD, GRL, SA, GV)
      SUMSA = SUMSA + 12.0*SA
      SUMGV = SUMGV + 12.0*GV
      CALL GENOS (S19 (1, 4), PRFD, GRL, .5*OD, SA, GV)
      SUMSA = SUMSA + 12.0*SA
      SUMGV = SUMGV + 12.0*GV
      SFAREA = SUMSA
      FRCSFA = SFAREA/S0
      VOLUNB = SUMGV
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*************************************************************************
C******************  CODE 10: ROUND-HEX 7-PERF GRAIN  ********************
C*************************************************************************
 1060 CONTINUE
      S0 = 6.0
      SI = 6.0
```

```
      NPERF = 7
      GO TO 1160
C*************************************************************************
C******************** CODE 11: CORD WITH INHIBITED ENDS ******************
C*************************************************************************
C This routine will only calculate the surface area of the lateral surfa
Cces.
C It will not calculate the surface area of the inhibited ends. ********
C*************************************************************************
 1100 CONTINUE
      SO = GL*PI*D
      VO = GL*PI*D**2/4.0
C **** This part does the calculations for the burning grain
      OD = AMAX1 (D - U, 0.0)
      SFAREA = PI*OD*GL
      FRCSFA = SFAREA/SO
      VOLUNB = GL*PI*OD**2/4.0
      VOLBRN = VO - VOLUNB
      FRCBRN = VOLBRN/VO
      RETURN
C*************************************************************************
C********** CODE 12: RECTANGULAR STRIP GRAIN WITH INHIBITED SIDES ******
C*************************************************************************
C This routine will only calculate the surface area of the two burning s
Cides.
C It will not calculate the surface area of the inhibited sides.
C*************************************************************************
 1110 CONTINUE
      SO = 2.0*GL*WI
      VO = GL*D*WI
      VOLMAO = (D - WI)*GL*WO
      VOLMBO = WI*GL*WO
C*************************************************************************
C *** This part does the calculations for the burning grain
      DS = AMAX1 (D - U, 0.0)
      SFAREA = 2.0*GL*WI
      FRCSFA = SFAREA/SO
      VOLUNB = GL*DS*WI
      VOLBRN = VO - VOLUNB
      FRCBRN = VOLBRN/VO
      IF (DS .GE. WI) THEN
         VOLABR = VOLBRN
         VOLBBR = 0.
      ELSE
         VOLABR = VOLMAO
         VOLBBR = VOLBRN - VOLABR
      END IF
      RETURN
      END
C*************************************************************************
C*************************************************************************
C
C  SUBROUTINE *GENIS*: calculate surface area and volume for a
C                      general inner sliver of a burning grain
```

```
C                        with length = GRL & perforation dia. = PRFD.
C
      SUBROUTINE GENIS (S, PRFD, GRL, SURF, VOL)
      DIMENSION S (3), A (4)
      DATA PI2/1.5707963/
C
C
C  **********  : Store angles A1,A2,A3 and area of triangle
C                with sides S(1),S(2),S(3) into A(1)...A(4)
C
      A (1) = ACOS ((S (2)**2 + S (3)**2 - S (1)**2)/(2.0*S (2)*S (3)))
      A (2) = ACOS ((S (1)**2 + S (3)**2 - S (2)**2)/(2.0*S (1)*S (3)))
      A (3) = ACOS ((S (1)**2 + S (2)**2 - S (3)**2)/(2.0*S (1)*S (2)))
      A (4) = 0.5*S (1)*S (3)*SIN (A (2))
C
C ...check for error condition: find if triangle acceptable...
C
      J = 0
      DO 1000 I = 1, 3
         IF (A (I) .LT. 0.5*PI2) J = J + 1
 1000 CONTINUE
      IF (J .GT. 1) STOP ' GENIS ERROR'
C
C
C  succeeding passes until burnout: find auxiliary angles
C
      TAU12 = ACOS (AMIN1 (1.0, S (3)/PRFD))
      TAU13 = ACOS (AMIN1 (1.0, S (2)/PRFD))
      TAU23 = ACOS (AMIN1 (1.0, S (1)/PRFD))
C
C  ...and branch to 25 if sliver fails burnout criteria. If not
C     then sliver is burned and go to 30.
C
      IF (TAU12 + TAU13 + TAU23 .LT. PI2 .AND. GRL .GT. 0.0) THEN
         GO TO 1010
      ELSE
         GO TO 1020
      END IF
C
C
C  sliver not burned out: determine end area, volume and surface area
C
 1010 CONTINUE
      E = A (4) - 0.25*PRFD*(S (1)*SIN (TAU23) + S (2)*SIN (TAU13)
     1    + S (3)*SIN (TAU12) + PRFD*(PI2 - TAU12 - TAU13 - TAU23))
C
      VOL = E*GRL
C
      SURF = 2.0*E + GRL*PRFD*(PI2 - TAU12 - TAU13 - TAU23)
C
C  ...and RETURN
C
      RETURN
C
```

```
C  sliver is burned out: return with zero volume and surface area.
C
 1020 CONTINUE
      VOL = 0.0
      SURF = 0.0
      RETURN
      END
C*****************************************************************
C  SUBROUTINE "GENOS" : Calculates surface area and volume for a
C                       general outer sliver of a burning grain
C                       with length = GRL, radius = RAD, and
C                       perforation diameter = PRFD
C
      SUBROUTINE GENOS (S, PRFD, GRL, RAD, SURF, VOL)
      DIMENSION S (3), A (4)
C
C ************   Store angles A1,A2,A3 and area of triangle
C                with sides S(1),S(2),S(3) into A(1) ...A(4)
C
      A (1) = ACOS ((S (2)**2 + S (3)**2 - S (1)**2)/(2.0*S (2)*S (3)))
      A (2) = ACOS ((S (1)**2 + S (3)**2 - S (2)**2)/(2.0*S (1)*S (3)))
      A (3) = ACOS ((S (1)**2 + S (2)**2 - S (3)**2)/(2.0*S (1)*S (2)))
      A (4) = 0.5*S (1)*S (3)*SIN (A (2))
C
C
C  succeeding passes until burnout: determine auxiliary angles
C
      TAU1 = ACOS (AMIN1 (1., (S (2)**2 + RAD**2 - 0.25*
     1   PRFD**2)/(2.*S (2)*RAD)))
      TAU2 = ACOS (AMIN1 (1., (S (3)**2 + RAD**2 - 0.25*
     1   PRFD**2)/(2.*S (3)*RAD)))
      TAU3 = ACOS (AMAX1 ( - 1.0, (S (2)**2 - RAD**2 + 0.25*
     1   PRFD**2)/(S (2)*PRFD)))
      TAU4 = ACOS (AMAX1 ( - 1.0, (S (3)**2 - RAD**2 + 0.25*
     1   PRFD**2)/(S (3)*PRFD)))
C
      SIG = ACOS (AMIN1 (1.0, S (1)/PRFD))
C
C ...then check error conditions...
C
      IF (TAU3 .LT. A (3) .OR. TAU4 .LT. A (2)) STOP ' *GENOS* ERROR'
C
C ...IF ok, check if sliver burned out. If not burned out go to 25.
C    If burned out go to 30.
C
      IF (TAU1 + TAU2 .LT. A (1) .AND. GRL .GT. 0.0) THEN
         GO TO 1000
      ELSE
         GO TO 1010
      END IF
C
C
C  sliver not burned out: determine end area, volume and surface area.
C
```

```
 1000 CONTINUE
      E = 0.5*RAD*(S (2)*SIN (TAU1) + RAD*(A (1) - TAU1 - TAU2)
     1    + S (3)*SIN (TAU2)) - A (4) - 0.25*PRFD*(S (1)*SIN (SIG)
     2    + 0.5*PRFD*(TAU3 + TAU4 - 2.0*SIG - A (2) - A (3)))
C
      VOL = E*GRL
C
      SURF = 2.0*E + GRL*(RAD*(A (1) - TAU1 - TAU2) + 0.5*PRFD*(TAU3
     1    + TAU4 - 2.0*SIG - A (2) - A (3)))
C
C ...and RETURN.
C
      RETURN
C
C  sliver is burned out: return with zero volume and surface area.
C
 1010 CONTINUE
      VOL = 0.0
      SURF = 0.0
      RETURN
      END
```

| No. of Copies | Organization |
|---|---|
| 2 | Administrator<br>Defense Technical Info Center<br>ATTN: DTIC-DDA<br>Cameron Station<br>Alexandria, VA 22304-6145 |
| 1 | Commander<br>U.S. Army Materiel Command<br>ATTN: AMCAM<br>5001 Eisenhower Ave.<br>Alexandria, VA 22333-0001 |
| 1 | Director<br>U.S. Army Research Laboratory<br>ATTN: AMSRL-OP-CI-AD,<br>Tech Publishing<br>2800 Powder Mill Rd.<br>Adelphi, MD 20783-1145 |
| 1 | Director<br>U.S. Army Research Laboratory<br>ATTN: AMSRL-OP-CI-AD,<br>Records Management<br>2800 Powder Mill Rd.<br>Adelphi, MD 20783-1145 |
| 2 | Commander<br>U.S. Army Armament Research,<br>Development, and Engineering Center<br>ATTN: SMCAR-IMI-I<br>Picatinny Arsenal, NJ 07806-5000 |
| 2 | Commander<br>U.S. Army Armament Research,<br>Development, and Engineering Center<br>ATTN: SMCAR-TDC<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Director<br>Benet Weapons Laboratory<br>U.S. Army Armament Research,<br>Development, and Engineering Center<br>ATTN: SMCAR-CCB-TL<br>Watervliet, NY 12189-4050 |
| (Unclass. only) 1 | Commander<br>U.S. Army Rock Island Arsenal<br>ATTN: SMCRI-IMC-RT/Technical Library<br>Rock Island, IL 61299-5000 |
| 1 | Director<br>U.S. Army Aviation Research<br>and Technology Activity<br>ATTN: SAVRT-R (Library)<br>M/S 219-3<br>Ames Research Center<br>Moffett Field, CA 94035-1000 |

| No. of Copies | Organization |
|---|---|
| 1 | Commander<br>U.S. Army Missile Command<br>ATTN: AMSMI-RD-CS-R (DOC)<br>Redstone Arsenal, AL 35898-5010 |
| 1 | Commander<br>U.S. Army Tank-Automotive Command<br>ATTN: ASQNC-TAC-DIT (Technical<br>Information Center)<br>Warren, MI 48397-5000 |
| 1 | Director<br>U.S. Army TRADOC Analysis Command<br>ATTN: ATRC-WSR<br>White Sands Missile Range, NM 88002-5502 |
| 1 | Commandant<br>U.S. Army Field Artillery School<br>ATTN: ATSF-CSI<br>Ft. Sill, OK 73503-5000 |
| (Class. only) 1 | Commandant<br>U.S. Army Infantry School<br>ATTN: ATSH-CD (Security Mgr.)<br>Fort Benning, GA 31905-5660 |
| (Unclass. only) 1 | Commandant<br>U.S. Army Infantry School<br>ATTN: ATSH-CD-CSO-OR<br>Fort Benning, GA 31905-5660 |
| 1 | WL/MNOI<br>Eglin AFB, FL 32542-5000 |
| | Aberdeen Proving Ground |
| 2 | Dir, USAMSAA<br>ATTN: AMXSY-D<br>AMXSY-MP, H. Cohen |
| 1 | Cdr, USATECOM<br>ATTN: AMSTE-TC |
| 1 | Dir, ERDEC<br>ATTN: SCBRD-RT |
| 1 | Cdr, CBDA<br>ATTN: AMSCB-CI |
| 1 | Dir, USARL<br>ATTN: AMSRL-SL-I |
| 10 | Dir, USARL<br>ATTN: AMSRL-OP-CI-B (Tech Lib) |

| No. of Copies | Organization |
|---|---|
| 1 | OSD/SDIO/IST<br>ATTN: Dr. Len Caveny<br>Pentagon<br>Washington, DC 20301-7100 |
| 1 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-QAH-T, Mr. John Domen<br>Building 62 North<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-AEE-BR,<br>Mr. Ken Klingaman<br>Building 1501<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-ASI, Dr. Jerry Rubin<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Director<br>U.S. Army BMD<br>Advanced Technology Center<br>P. O. Box 1500<br>Huntsville, AL 35807 |
| 1 | Chairman<br>DOD Explosives Safety Board<br>Room 856-C<br>Hoffman Bldg. 1<br>2461 Eisenhower Ave.<br>Alexandria, VA 22331-0600 |
| 1 | Department of the Army<br>Office of the Product Manager<br>155mm Howitzer, M109A6, Paladin<br>ATTN: SFAE-AR-HIP-IP, Mr. R. De Kleine<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Commander, USACECOM<br>R&D Technical Library<br>ATTN: ASQNC-ELC-IS-L-R, Myer Center<br>Fort Monmouth, NJ 07703-5301 |

| No. of Copies | Organization |
|---|---|
| 3 | PEO-Armaments<br>Project Manager<br>Tank Main Armament Systems<br>ATTN: AMCPM-TMA, K. Russell<br>AMCPM-TMA-105<br>AMCPM-TMA-120<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Commander<br>Production Base Modernization Agency<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: AMSMC-PBM-E, L. Laibson<br>Picatinny Arsenal, NJ 07806-5000 |
| 5 | Director<br>Benet Laboratories<br>U.S. Army Watervliet Arsenal<br>ATTN: SARWV-RD,<br>G. Carafano<br>R. Thierry<br>R. Hasoenbein<br>P. Votis<br>P. Alto<br>Watervliet, NY 12189 |
| 3 | Commander<br>U.S. Army AMCCOM<br>ATTN: AMSMC-IRC, G. Cowan<br>SMCAR-ESM(R),<br>W. Fortune<br>R. Zastrow<br>Rock Island, IL 61299-7300 |
| 1 | Commandant<br>U.S. Army Aviation School<br>ATTN: Aviation Agency<br>Fort Rucker, AL 36360 |
| 1 | Director<br>HQ, TRAC RPD<br>ATTN: ATCD-MA, MAJ Williams<br>Fort Monroe, VA 23651-5143 |
| 1 | Headquarters<br>U.S. Army Materiel Command<br>ATTN: AMCICP-AD, Michael F. Fisette<br>5001 Eisenhower Ave.<br>Alexandria, VA 22333-0001 |

| No. of Copies | Organization |
|---|---|
| 4 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-CCD, D. Spring<br>SMCAR-CCS<br>SMCAR-CCH-T, L. Rosendorf<br>SMCAR-CCH-V, E. Fennell<br>Picatinny Arsenal, NJ 07806-5000 |
| 8 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-AE, J. Picard<br>SMCAR-AEE-B,<br>A. Beardell<br>D. Downs<br>S. Einstein<br>A. Bracuti<br>D. Chiu<br>SMCAR-AEE, J. Lannon<br>SMCAR-AES, S. Kaplowitz<br>Picatinny Arsenal, NJ 07806-5000 |
| 7 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-FSA-T, M. Salsbury<br>SMCAR-FSE,<br>T. Gora<br>B. Knutelsky<br>K. C. Pan<br>W. Davis<br>C. Durham<br>A. Graf<br>Picatinny Arsenal, NJ 07806-5000 |
| 6 | Commander<br>U.S. Army Armament Research, Development, and Engineering Center<br>ATTN: SMCAR-EG,<br>G. Ferdinand<br>H. Naber-Libby<br>R. Lundberg<br>J. Niles<br>R. Moreira<br>W. Morelli<br>Picatinny Arsenal, NJ 07806-5000 |
| 2 | Commander<br>U.S. Army Research Office<br>ATTN: Technical Library<br>D. Mann<br>P.O. Box 12211<br>Research Triangle Park, NC 27709-2211 |
| 1 | Commander<br>U.S. Army Belvoir R&D Center<br>ATTN: STRBE-WC,<br>Technical Library (Vault)<br>Bldg. 315<br>Fort Belvoir, VA 22060-5606 |
| 1 | Commander<br>U.S. Army TRAC - Fort Lee<br>Defense Logistics Studies<br>Fort Lee, VA 23801-6140 |
| 1 | President<br>U.S. Army Artillery Board<br>Fort Sill, OK 73503 |
| 1 | Commandant<br>U.S. Army Command and General Staff College<br>Fort Leavenworth, KS 66027-5200 |
| 1 | Commandant<br>U.S. Army Special Warfare School<br>ATTN: Rev and Tng Lit Div<br>Fort Bragg, NC 28307 |
| 1 | Commander<br>Radford Army Ammunition Plant<br>ATTN: SMCRA-QA/HI Library<br>Radford, VA 24141 |
| 1 | Commandant<br>U.S. Army Field Artillery School<br>ATTN: STSF-TSM-CN<br>Fort Sill, OK 73503-5600 |
| 4 | Deputy Commander<br>Strategic Defense Command<br>ATTN: SFAE-SD-HVL,<br>S. Smith<br>LTC Kee<br>D. Lianos<br>T Aden<br>P.O. Box 1500<br>Huntsville, AL 35887-8801 |

| No. of Copies | Organization |
|---|---|
| 3 | Commander<br>U.S. Army Foreign Science and Technology Center<br>ATTN: AMXST-MC-3,<br>S. LeBeau<br>C. Beiter<br>220 Seventh St., NE<br>Charlottesville, VA 22901 |
| 1 | Commandant<br>U.S. Army Field Artillery Center and School<br>ATTN: ATSF-CO-MW, B. Willis<br>Fort Sill, OK 73503 |
| 1 | Naval Sea System Command<br>Department of the Navy<br>ATTN: CSEA, CDR Dampier<br>06KR12<br>Washington, DC 20362-5101 |
| 1 | Office of Naval Research<br>ATTN: Code 473, R. S. Miller<br>800 N. Quincy St.<br>Arlington, VA 22217 |
| 2 | Commander<br>Naval Sea Systems Command<br>ATTN: SEA 62R<br>SEA 64<br>Washington, DC 20362-5101 |
| 1 | Commander<br>Naval Air Systems Command<br>ATTN: AIR-954-Technical Library<br>Washington, DC 20360 |
| 1 | Naval Research Laboratory<br>Technical Library<br>Washington, DC 20375 |
| 2 | Commander<br>Naval Surface Warfare Center<br>ATTN: J. P. Consaga<br>C. Gotzmer<br>Silver Spring, MD 20902-5000 |
| 2 | Commander<br>Naval Surface Warfare Center<br>ATTN: K. Kim/Code R-13<br>R. Bernecker/Code R-13<br>Silver Spring, MD 20902-5000 |

| No. of Copies | Organization |
|---|---|
| 3 | Commander<br>Naval Surface Warfare Center<br>Indian Head Division<br>ATTN: 610, C. Smith<br>6110J, K. Rice<br>6110C, S. Peters<br>Indian Head, MD 20640-5035 |
| 6 | Commander<br>Dahlgren Division<br>Naval Surface Warfare Center<br>ATTN: Code G33,<br>T. Doran<br>J. Copley<br>Code G30, Guns and Munitions Division<br>Code G301, D. Wilson<br>Code G32, Guns Systems Division<br>Code E23, Technical Library<br>Dahlgren, VA 22448-5000 |
| 1 | Commander<br>Naval Surface Weapon Center<br>Indian Head Division<br>ATTN: Code 270P1, Mr. Ed Chan<br>101 Straus Avenue<br>Indian Head, MD 20640 |
| 1 | Commander<br>Naval Surface Weapon Center<br>Indian Head Division<br>ATTN: Code 3120, Mr. Robert Rast<br>101 Straus Avenue<br>Indian Head, MD 20640 |
| 1 | Commander<br>Naval Surface Weapon Center<br>Indian Head Division<br>ATTN: Code 210P1, Mr. Ron Simmons<br>101 Straus Avenue<br>Indian Head, MD 20640 |
| 2 | Commander<br>Naval Surface Weapon Center<br>Indian Head Division<br>ATTN: Code 6210,<br>Sharon Boyles<br>Norberto Almeyda<br>101 Straus Avenue<br>Indian Head, MD 20640 |

| No. of Copies | Organization |
|---|---|
| 1 | Naval Air Warfare Center<br>ATTN: Code 3891, Mr. Chan Price<br>China Lake, CA 93555 |
| 1 | Commander<br>Naval Air Warfare Center<br>ATTN: Code 3891, Ms. Alice Atwood<br>China Lake, CA 93555 |
| 1 | Commander<br>Naval Weapons Center<br>ATTN: Code 388, C. F. Price<br>Info Science Div<br>China Lake, CA 93555-6001 |
| 1 | OLAC PL/TSTL<br>ATTN: D. Shiplett<br>Edwards AFB, CA 93523-5000 |
| 10 | Central Intelligence Agency<br>Office of Central Reference Dissemination Branch<br>Room GE-47 HQS<br>Washington, DC 20502 |
| 1 | Central Intelligence Agency<br>ATTN: Joseph E. Backofen<br>HQ Room 5F22<br>Washington, DC 20505 |
| 5 | Director<br>Sandia National Laboratories<br>ATTN: T. Hitchcock<br>R. Woodfin<br>D. Benson<br>S. Kempka<br>R. Beasley<br>Advanced Projects Div 14<br>Organization 9123<br>Albuquerque, NM 87185 |
| 2 | Director<br>Los Alamos National Laboratory<br>ATTN: B. Kaswhia<br>H. Davis<br>Los Alamos, NM 87545 |

| No. of Copies | Organization |
|---|---|
| 1 | Director<br>Lawrence Livermore National Laboratory<br>ATTN: M. S. L-355, A. Buckingham<br>P.O. Box 808<br>Livermore, CA 94550 |
| 2 | Director<br>Sandia National Laboratories<br>Combustion Research Facility<br>ATTN: R. Armstrong<br>S. Vosen<br>Division 8357<br>Livermore, CA 94551-0469 |
| 1 | University of Illinois<br>Dept. of Mech./Indust. Engr.<br>ATTN: Professor Herman Krier, 144 MEB<br>1206 N. Green St.<br>Urbana, IL 61801 |
| 1 | The Johns Hopkins University/CPIA<br>ATTN: T. Christian<br>10630 Little Patuxent Parkway, Suite 202<br>Columbia, MD 21044-3200 |
| 2 | Pennsylvania State University<br>Dept. of Mechanical Engr.<br>ATTN: Jeff Brown<br>312 Mechanical Engineering Bldg.<br>University Park, PA 16802 |
| 1 | North Carolina State University<br>ATTN: John G. Gilligan<br>Box 7909<br>1110 Burlington Engineering Labs<br>Raleigh, NC 27695-7909 |
| 2 | Institute for Advanced Studies<br>ATTN: Dr. H. Fair<br>Dr. T. Kiehne<br>4030-2 West Baker Lane<br>Austin, TX 78759-5329 |
| 1 | SRI International<br>Propulsion Sciences Division<br>ATTN: Technical Library<br>333 Ravenswood Ave.<br>Menlo Park, CA 94025 |

| No. of Copies | Organization |
|---|---|
| 1 | SPARTA<br>ATTN: Dr. Michael Holland<br>9455 Towne Center Dr.<br>San Diego, CA 92121-1964 |
| 5 | FMC Corporation<br>ATTN: Mr. G. Johnson<br>Mr. M. Seale<br>Dr. A. Giovanetti<br>Mr. J. Dyvik<br>Dr. D. Cook<br>4800 East River Rd.<br>Minneapolis, MN 55421-1498 |
| 2 | Hercules Inc.<br>Radford Army Ammunition Plant<br>Manager Manufacturing Engineering Department<br>ATTN: D. A. Worrell<br>Edward Sanford<br>P.O. Box 1<br>Radford, VA 24141 |
| 1 | Hercules Inc.<br>ATTN: Dr. Richard Cartwright<br>100 Howard Blvd.<br>Kenvil, NJ 07847 |
| 3 | GT Devices<br>ATTN: Dr. S. Goldstein<br>Dr. R. J. Greig<br>Dr. N. Winsor<br>5705A General Washington Dr.<br>Alexandria, VA 22312 |
| 3 | General Dynamics Land Systems<br>ATTN: Dr. B. VanDeusen<br>Mr. F. Lunsford<br>Dr. M. Weidner<br>P.O. Box 2074<br>Warren, MI 48090-2074 |
| 2 | Alliant Techsystems, Inc.<br>ATTN: R E. Tompkins<br>J. Kennedy<br>7225 Northland Drive<br>Brooklyn Park, MN 55428 |

| No. of Copies | Organization |
|---|---|
| 4 | Olin Ordnance<br>ATTN: V. McDonald, Library<br>Hugh McElroy<br>Mr. Thomas Bourgeois<br>Mr. Dennis Worthington<br>P.O. Box 222<br>St. Marks, FL 32355 |
| 1 | Paul Gough Associates, Inc.<br>ATTN: P. S. Gough<br>1048 South St.<br>Portsmouth, NH 03801-5423 |
| 1 | Physics International Library<br>ATTN: H. Wayne Wampler<br>P.O. Box 5010<br>San Leandro, CA 94577-0599 |
| 2 | Rockwell International<br>Rocketdyne Division<br>ATTN: BA08,<br>J. E. Flanagan<br>J. Gray<br>6633 Canoga Ave.<br>Canoga Park, CA 91304 |
| 2 | Princeton Combustion Research Laboratories, Inc.<br>ATTN: M. Summerfield<br>N. Messina<br>Princeton Corporate Plaza<br>11 Deerpark Drive<br>Bldg. IV, Suite 119<br>Monmouth Junction, NJ 08852 |
| 2 | Science Applications, Inc.<br>ATTN: J. Batteh<br>L. Thornhill<br>1519 Johnson Ferry Rd.<br>Suite 300<br>Marietta, GA 30062-6438 |
| 1 | Eli Freedman & Associates<br>ATTN: E. Freedman<br>2411 Diana Rd.<br>Baltimore, MD 21209 |

| No. of Copies | Organization |
|---|---|
| 1 | Rocketdyne<br>ATTN: Mr. Otto Heiney<br>Mail Stop BA26<br>6633 Canoga Avenue<br>Conoga Park, CA 91304 |
| 1 | Thiokol (Longhorn Division)<br>ATTN: Dr. David Dillehay<br>Mail Stop 703-11<br>P.O. Box 1149<br>Marshall, TX 75671 |
| 1 | Thiokol (Elkton Division)<br>ATTN: Dr. Rodney Willer<br>55 Thiokol Road<br>Elkton, MD 21922 |
| 1 | Veritay Technology, Inc.<br>ATTN: Mr. E. Fisher<br>4845 Millersport Highway<br>East Amherst, NY 14051-0305 |
| 1 | Veritay Technology, Inc.<br>4845 Millersport Hwy.<br>P.O. Box 305<br>East Amherst, NY 14051-0305 |
| 1 | Battelle<br>ATTN: TACTEC Library, J. N Huggins<br>505 King Ave.<br>Columbus, OH 43201-2693 |
| 2 | California Institute of Technology<br>Jet Propulsion Laboratory<br>ATTN: L. D. Strand, MS 125-224<br>D. Elliot<br>4800 Oak Grove Dr.<br>Pasadena, CA 91109 |
| 1 | General Electric Co.<br>Defense Systems Division<br>ATTN: Dr. J. Mandzy<br>Mail Drop 43-220<br>100 Plastics Ave.<br>Pittsfield, MA 01201 |
| 2 | SAIC<br>ATTN: Mr. N. Sinha<br>Dr. S. Dash<br>501 Office Center Drive<br>Fort Washington, PA 19034-3211 |

| No. of Copies | Organization |
|---|---|
| 1 | State University of New York<br>Department of Electrical Engineering<br>ATTN: Dr. W. J. Sargeant<br>Bonner Hall - Room 312<br>Buffalo, NY 14260 |
| 1 | Science Application International Corporation<br>ATTN: Dr. George Chryssamellis<br>8400 Normandele Blvd.<br>Suite 939<br>Minneapolis, MN 55437 |
| 1 | Hercules, Inc.<br>ATTN: Dr. Richard Cartwright<br>100 Howard Blvd.<br>Kenvil, New Jersey 07847 |
| 1 | Sandia National Laboratories<br>ATTN: Mr. Mark Grubelich, DIV 2515<br>P.O. Box 5800<br>Albuquerque, NM 87185 |
| 1 | IMI Services USA<br>ATTN: Mr. G. Rashba<br>2 Wisconsin Circle<br>Suite 420<br>Chevy Chase, MD 20815 |
| | Aberdeen Proving Ground |
| 4 | Cdr, USACSTA<br>ATTN: S. Walton<br>G. Rice<br>D. Lacey<br>C. Herud |

No. of
Copies Organization

2 RARDE
GS2 Division
Building R31
ATTN: Dr. C. Woodley
Dr. G. Cook
Fort Halstead
Sevenoaks, Kent TN14 7BP
ENGLAND

1 Materials Research Laboratory
Salisbury Branch
ATTN: Anna Wildegger Gaissmaier
Explosives Ordnance Division
Salisbury South Australia 5108

1 Laboratorio Quimico Central de Armamento
ATTN: Captain Juan F. Hernandez Tamayo
Apartado 1105
28080 Madrid
SPAIN

1 R&D Department
ATTN: Dr. Pierre Archambault
5 Montee des Arsenaux
Le Gardeur, Quebec, Canada J5Z 2P4

1 TZN Forschungs- und Entwicklungszentrum
ATTN: Mr. T. Weise, Dr.-Ing.
Abt. SE, Fachbereich:
Hochleistungspulstechnik
Neuensothriether Straße 20
D-3104 Unterlüh, Germany

1 Ernst-Mach-Institut
ATTN: Dr. Gustav-Adolf Schröder
Hauptstraße 18
D-7858 Weil am Rhein, Germany

2 Institut Franco-Allemand
ATTN: Dr. M. Samirant
Mr. D. Grune
F 68301 SAINT-LOUIS Cédex, 12,
rue de l'Industrie, B.P. 301, France

## USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number ARL-MR-61 Date of Report April 1993

2. Date Report Received _____

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) _____

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) _____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. _____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) _____

CURRENT ADDRESS

_____
Organization

_____
Name

_____
Street or P.O. Box No.

_____
City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

_____
Organization

_____
Name

_____
Street or P.O. Box No.

_____
City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)
(DO NOT STAPLE)